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There is some tradition of reflecting telescopes in classical times, probably groundless save as the ancients had concave mirrors and these, if of fairly long focus, would present to the eye an enlarged image of a distant object.

The first suggestion that a mirror might be used instead of an objective seemed to have come from Mersenne about the middle of the seventeenth century in a letter to Descartes. The idea did not appeal to the latter and the matter was dropped. The first actual reflecting telescope was designed by James Gregory, who published an account of it in his "Optica Promota" in 1663. In this he described the rather elegant construction which still bears his name, a perforated parabolic mirror with an elliptical concave mirror placed beyond its focus and returning an erect image to the ocular through the perforation.

The next year Gregory started Reive, a well known London optician, at making a 6 foot telescope. This failed on account of inability to get the necessary figure, largely owing to the fact that Reive tried to polish his mirrors on cloth, never a satisfactory material for accurate figuring. It is possible that Gregory had better luck later, for there is a well defined tradition that he died from a stroke of apoplexy in 1675 while showing to a group of students Jupiter's moons through one of his own telescopes. Certainly Robert Hooke presented a passable example to the Royal Society at its meeting February 5, 1673–4.

Now enters upon the scene the biggest figure of the period in science, Isaac Newton, then a young man who had just discovered the dispersion of light. A great speculative philosopher and mathematician, he was neither a practical astronomer nor a particularly good experimenter, and failed to discover the difference of relative dispersion in refractive media by the inexcusable blunder of raising the refraction of the water with which he was comparing glass by loading it with sugar of lead, and then jumping at the conclusion that all substances varied equally both in refraction and dispersion.

In other words he assumed without real investigation that the quantity which we now know as ν was a constant for all substances.

Just how this singularly maladroit piece of experimentation leaked out is unknown, although the fact is stated in the most positive manner both by Sir David Brewster, Newton's admiring biographer, and by Sir John Herschel. It is not unlikely that the fact got abroad at Cambridge in Newton's later years, and was passed along to Sir William Herschel. Certainly, as one of Newton's later apologists naïvely suggests, the fact was not recorded in Newton's "Opticks."

Be that as it may, it was the kind of thing for which a second-year student in physics would get a wigging which would linger long in his memory, but a blunder with a great name behind it carries far, and in this case it put off for a couple of generations the discovery of the principle of achromatism.

Following his error, Newton gave up all idea of an achromatic lens, and turned his attention to reflectors, apparently being unacquainted with, or entirely disregarding, what James Gregory had done before him. Newton had taken to the country on account of the plague, and only about 1670 did he apparently begin to revolve in his mind a reflecting telescope. It was 1672, January 11th, when he presented to the Royal Society a small model of his preferred form of reflector, which is still in the possession of the Society.

This little model had an aperture of about 1″ and focal length of about 6″, and magnified some 38 diameters. Newton was able, he says, to detect with it the moons of Jupiter and the horns of Venus, both feats which can be accomplished with the very slightest of optical aid, providing the magnification is anywhere near that which Newton used. But here again Newton gave notable evidence of his unpractical experimenting, clever though he was.

He had firmly fixed in his mind the entirely erroneous idea that a spherical mirror was quite good enough for the purpose, even when an aperture of F/6 or F/8 was used, believing that the trouble with the long telescopes of the day was almost entirely their chromatic aberration. This was partly true, but the spherical aberrations would have been equally bad save for the very narrow aperture employed.

This error would certainly have brought Newton to grief had he attempted a telescope of any perceptible size and in fact there is some evidence that this actually happened. On January 25th, just two weeks after his model was displayed, the minutes of the Royal Society note that: "There was produced a reflecting telescope 4 feet long of Mr. Newton's invention which though the metaline concave was not

duly polished yet did pretty well, but was under charged. It was ordered to be perfected against the next meeting."

At the next meeting the following: — "The 4 foot telescope of Mr. Newton's invention was produced again, being improved since the last meeting. It was recommended to Mr. Hooke to see it perfected as far as it was capable of being." So far as the annals record it never again appeared on the scene.

While it was not definitely stated by whom this telescope was made an entry of March 1st of the same year in the Journal de Sçavans definitely ascribes this 4 foot telescope to Newton, although the account is rather vague. It would look therefore as though Newton himself or some of his friends had tried out his invention on a larger scale, and had fallen into exactly the trouble that might have been expected.

Perhaps Newton's aversion to the paraboloid, of which he knew perfectly well the properties, may have been partly due to the fact, as stated in one of his letters, that there is no strictly geometrical method of grinding it. About the same time Hooke proposed to stamp up the specula out of silver and before the end of the year he was working on a 15 inch mould for a speculum of 10 feet focal length, of which nothing has since been heard.

Meanwhile enters upon the scene the personage known in the histories of science as "Cassegrain, a Frenchman." A communication from M. DeBercé to the Royal Society describes his invention and gives a very rough sketch of it. This was a translation of a letter sent by DeBercé to the Academy of Sciences from Chartres, and read at the séance of April 16, 1672. DeBercé says that this invention had been communicated by Cassegrain to him some three months previously, and how much before this time Cassegrain had been working on the problem will probably never be discovered. At all events the Cassegrainian telescope was disclosed to others than the inventor at substantially the same time as Newton's and was certainly an independent invention, although one letter to the Royal Society vigorously berates the Frenchman for stealing "Our Newton's" thunder, and explains how an ingenious friend of the writer is making a still further improvement on Cassegrain's form by using a flat secondary speculum.

Newton's comment on DeBercé's letter plainly shows that he did not enjoy a rival in the field, for it is somewhat discouraging in tone and incidentally his specific criticisms were consistently wrong, as for instance he had the erroneous idea that speculum metal reflects much better at 45° incidence than at normal incidence, whereas in fact the

difference is too small for even its sign to be distinguished with certainty. It is the irony of time that the Cassegrainian form is the one which has survived in the greatest instruments of the present time.

The writer is glad to be able to drag "Cassegrain, a Frenchman," from something of the obscurity in which he has been veiled, introducing then, Sieur Guillaume Cassegrain, sculptor in the service of his glorious Majesty Louis Quatorze, modeller and founder of statues for the decoration of the king's gardens at Versailles.

In 1666 he cast a bust of the King, after Bertin's model, for which he received 1200 livres, and for the next twenty years or thereabouts made also many replicas from the antique, including groups like the Laocoön receiving payments from the Royal Treasury for his artistic services well into the year 1684, at which time we lose sight of him. He is believed to have died in the period between 1684 and 1686. Cassegrain like his friend DeBercé was of Chartres, a city long consecrated to the art of sculpture. At about the same time that DeBercé sent to the Academy of Sciences the little note on Cassegrain's telescope, Cassegrain himself wrote a long letter to the Academy concerning the speaking trumpet lately invented by Sir Samuel Morland.

It was in this letter that the writer got the first clew to Cassegrain's identity, since in it he displays beautiful draughtsmanship, as shown in the accompanying copper plate, in striking contrast with his friend's rough sketch, and also a notable familiarity with the art of bell founding, which very likely may have been practiced in his own atelier. In fact he writes like an educated and experienced artist, and was obviously regarded as a person of some consequence, for this letter formed the *piéce de resistance* at the meeting of the Academy of Sciences on the 2nd of May 1672. When and where Cassegrain was born one cannot tell with any certainty, although it is not unlikely to have been somewhere about 1630 to 1635, quite possibly in Chartres. At all events his profession and facilities were such as would very readily have led him toward a reflecting telescope if a hint of Mersenne's suggestion to Descartes, or of James Gregory's theory, had come to his notice.

Note that in the account of Newton's telescope in the Journal de Sçavans the word is used in its modern English sense instead of being, as now, confined in French to reflectors, while the Cassegrainian instrument is spoken of as a little "lunette d'approche." One does not generally suggest dimensions for a thing non-existent. Whether Cassegrain actually made and experimented with telescopes nobody

actually knows, but as a founder, familiar with bronze and bell metal, it is not unlikely that he tried it.

It was bell metal, by the way, which was the basis of Newton's speculum metal. He merely whitened it a little with arsenic, as the alchemists had done before him, thinking the alloy one stage in the transmutation of copper to silver. Bell metal ranged in early times from one part tin to four of copper, to one part tin to two of copper. Newton's was very likely between the two, since he recommends one of tin to three of copper, a material which works and polishes well, but tarnishes with great rapidity, as Sir William Herschel found to his cost many years later.

Exit now the reflector, for more than about half a century. Newton made one more try at it, working on a 4 inch glass speculum to be silvered on the back after the plan early proposed by Gregory. The instrument was apparently never completed.

Another item often ascribed to Newton was the discovery of pitch polishing. That he found the process to work well is undeniable, but he did not disclose it for more than thirty years after his little telescope had been laid on the shelf of the Royal Society, in fact not until several years after there had been published, subsequent to Huygens' death, the fact that he had been in the habit of polishing his true tools for lens grinding in exactly this manner.

It was not until Newton was a venerable invalid, a half century after his telescope had been put away and forgotten, that the reflecting instrument was finally put upon the stage by John Hadley, the inventor of the reflecting octant.

Hadley knew enough to make his own speculum metal and in his struggles with it derived very little information from Newton's experimentation. He realized the importance of parabolizing his main mirror and of giving a hyperbolic figure to his small mirror. He polished them both not directly upon pitch, but upon pitch over-laid with the finest silk fabric, which apparently helped in distributing and holding the abrasive, and in 1722 presented to the Royal Society the first veritable reflecting telescope.

This instrument was of about 6 inches aperture and of about 5 feet focal length and proved on test to be better than the telescope of 123 feet focus belonging to the Royal Society and made by Huygens. The tests of the telescope show that it had a pretty good figure, and in fact Hadley hit upon the method of testing for figure used for many years thereafter, by examining the speculum at the centre of curvature and judging of the parabolic figure by the default of the image from the characteristics of a spherical mirror.

John Hadley in fact was the real inventor of the reflector in quite the same sense that Mr. Edison invented the incandescent lamp; from grasping the true principles of the matter and carrying them out to success while the only previous attempts had ended in dismal failure.

It was Hadley who taught the art to Molyneux and others and to whom James Short, the most celebrated of eighteenth century artists until the time of Herschel, was undoubtedly indebted for the start upon his brilliant career.

Short, however, worked to the Gregorian principle with success, doubtless since because this telescope rectifies the image, it is available both for terrestrial and celestial use. He made instruments from all accounts of beautiful figure, some of them up to 8 or 10 inches diameter, and of a speculum metal so nicely compounded and polished that some of his specula were still serviceable well toward the end of the nineteenth century.

There is good reason to suspect that Short may have been the inventor of the system of distributed grooves given to the tools, upon which successful figuring so much depends, since, dying, he ordered the destruction of his whole equipment, a quite needless precaution against the success of posterity had there not been very radical improvements, easily detected. James Short, too, was the first constructor of genuine equatorial mountings of which he executed several about the middle of the eighteenth century. He died leaving the methods which led him to success a mystery unsolved, for Herschel and his successors to puzzle over. The only change in the situation after Herschel's day was the independent invention of Steinheil and Foucault which gave to silver-on-glass its present supremacy. The earliest examples of Foucault's work show how little, otherwise than in the material and figuring of the speculum, the art of telescope construction had progressed since Hadley and Short were working a century before.